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WADC TECHNICAL REPORT 57-351-1
SUPPLEMENT 1

THE INFLUENCE OF GEOMETRY PARAMETERS UPON LAG ERROR IN AIRBORNE PRESSURE MEASURING SYSTEMS—SUPPLEMENT 1

J. P. LAMB JR., 1ST LT, USAF
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INSTRUMENT BRANCH
FLIGHT CONTROL LABORATORY
CONTRACT NO. AF 33(600)-32250

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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100 — January 1958

FORWARD

This report was initiated by the Flight Control Laboratory, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio and presents the results of static pressure lag tests on two tubing arrangements for the F-106 aircraft utilizing various pitot-static tube sensors. The data contained herein supplements the pressure lag investigation conducted by Lt. J. P. Lamb and reported in WADC Technical Report No. 57-351 "The Influence of Geometry Parameters Upon Lag Errors in Airberne Pressure Measuring Systems". In accordance with Contract AF 33(600)- 32250 and Test Request dated 14 May 1957, the Inland Testing Laboratories of Dayton, Ohio under the supervision of Lt. Lamb arranged the mock-up static pressure system and conducted the tests. Mr. Paul E. Blatt was author of the supplement.

ABSTRACT

Pitot-static sensor design greatly influences the lag in pressure transmission from the sensor to the connected equipment during high speed maneuver. An investigation of the effects of five different static pressure chambers on the overall system lag was conducted on a F-106 aircraft mock-up with 3/8 inch O.D X 0.035 inch wall thickness connecting tubing. Results of the tests indicate that the design and dimensions of the static pressure chamber can increase the total static pressure system lag by as much as a factor of 7.16 over an optimum chamber design at 40,000 feet altitude.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Roy C. Smith, Lt Col
for JOHN L. MARTIN, JR
Colonel, USAF
Chief, Flight Control Laboratory

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SECTION I

INTRODUCTION

The primary lag investigation indicated the importance of the pitot-static tube design on the overall static pressure lag to the associated equipment, so the lag experimentation was extended to include the effects of five different static pressure chamber designs on the optimum F-106 aircraft static pressure system determined in the previous report. Although the exact magnitude of the lag constant will vary with aircraft design depending upon lengths of tubing and the volume of the connected equipment, all nose boom mounted pitot-static tubes should exhibit similar effects on the overall lag and the comparison between the geometric systems will be consistant with all similar aircraft.

Design of the pitot-static tube for service type aircraft is limited from a lag standpoint in that the tube should be of minimum diameter to limit the overall length, weight and electrical power required for icing protection. One method has been to provide an annular static pressure chamber between the heater element and the pitot pressure line. This has a definite disadvantage in that the air flow during high rates of dive or climb must pass over two frictional surfaces which induce increased lag. As referenced in the primary report, the equivalent diameter (diameter of simple tube of unit length which would have a lag equivalent to a given annular chamber) for such a construction is given by the equation:

$$D_{eq}^4 = D_1^4 - D_2^4 - \frac{(D_1^2 - D_2^2)^2}{\ln \frac{D_1}{D_2}}$$

where D_1 and D_2 are respectively the outer and inner diameters of the annulus. Therefore an annular chamber having an area equivalent to that of 1/4 inch O.D.x0.035 tubing in which $D_2 = 0.25$ and $D_1 = 0.308$ actually has the same lag as a simple tube with a 0.0914 inch diameter. No advantage in size based on response is gained by such a design. Also from an aerodynamic standpoint small static orifices are advantageous but in turn degrade the response of the overall system. Present research data indicates that the optimum point for the static orifices on a cylindrical probe is at 12 to 13 tube body diameters behind the nose and at a radial position of 37.5 degrees from the bottom vertical center point. The lag effect can best be reduced by drilling another set of orifices directly behind the first pair.

In an attempt to increase reliability and response to the Central air data computer, some airframe Contractors have investigated a pitot-static tube having dual static sources in which one source supplies static pressure to the central air data computer and the other source supplies the flight instruments and other related equipment. The result has been a tube weighing in the neighborhood of 2.5 pounds and requiring at least 720 watts to deice. The primary report indicates that a single 3/8 inch O.D. tubing arrangement provides slightly better response to the CADC and much greater response to the flight instruments then the dual source tube with twin 1/4 inch O.D. lines. Almost identical results are obtained when two 1/4 inch lines are teed directly behind the pitot-static tube.

SECTION II

TEST PROGRAM

2.1 Test Equipment and Techniques

The static pressure system of the F-106 aircraft was mocked up utilizing 3/8 inch X.035 tubing with simulated instrument volumes as shown in Figure I. Five pitot-static tubes were then tested on this basic system to determine the effect of the static pressure chamber design on static pressure lag. A second system was fabricated with two ¼ inch O.D. X 0.035 tubes teed directly behind the pitot-static tube as shown in Figure 2 (referred to hereafter as System 2) and two pitot-static tubes were tested on this system. Actual pitot-static tubes were tested where possible, but for some of the designs it was necessary to fabricate mockups of the static pressure chamber. The following is a description of the pitot-static tubes tested:

Part 1. MA-1 Developmental Tube having an annular static pressure chamber equivalent in area to that of a ¼ O.D. X .035 inch tube with an inner diameter of 0.25 inch and an outer diameter of 0.308 inch.

Part 2. A simulated annular static pressure chamber having the dimensions of the production MA-1 pitot-static tube with an inner diameter of 0.236 inch and an outer diameter of 0.3857 inch. The chamber was fabricated as shown in Figure 3.

Part 3. A tubular static pressure chamber 3/8 inch O.D. X 0.035 inch with twin static orifices drilled as shown in Figure 4. This design provided a minimum lag characteristic and was used as a basis of comparison for all other designs tested.

Part 4. A ¼ inch O.D. tubular chamber identical to Part 3 except for the outside diameter. See Figure 5 for dimensions.

Part 5. A service type AN5816 pitot-static tube which is installed on F-86, F-102 and F-104 aircraft and the first few F-106 aircraft. This tube has a 3/16 inch O.D. static pressure line leadout from the chamber to the coupling.

The method of determining the lag was identical to that of the primary report in which the pitot-static tube was mounted in an evacuated chamber and a constant rate of flow into the chamber was obtained by the use of calibrated chocked orifices as shown in Figure 6. Pressure transducers measured the pressure drop between the large chamber and the various instrument volumes and the outputs of the transducers were recorded by oscillograph. The main chamber was evacuated to a pressure equivalent to 80,000 feet and then reduced to sea level pressure at the rate of 0.1, 0.2, 0.3, and 0.4 pounds per square inch per second. An unstable pressure condition existed between the chamber and the system volumes due to the initial inrush of air when the chamber valve was opened. This transient condition stabilized at a pressure equivalent to approximately 50,000 feet and then became a constant rate. Data was reduced from the oscillograph record at intervals of approximately 10,000 feet.

The total experimental lag constant (viscous lag plus acoustic lag) was determined by dividing the pressure drop in pounds per square inch by the input rate in pounds per square inch per second for each individual group of instruments. The lag constant in seconds was plotted versus altitude in feet for each system and pitot-static tube for each input rate. The curve was then averaged between input rates to obtain a workable lag constant. Figures 7 through 11 present the results of the lag investigation versus altitude. System No. 2 lag results are presented in Figures 12 and 13.

2.2 Test Results and Analysis

Considerable scatter existed between the experimental lag constants with various input rates at high altitudes. This was determined to be the effects of an increase in Reynolds Number as the flow changed from laminar to transitional. Consistant curves were obtained for the individual pressure rate inputs so the orifice method of rate input could not be questioned.

Results of this investigation prove the vast importance of the static source design on the overall lag of the static pressure system.

Using the 3/8 inch O.D. tubular static pressure chamber (Part 3) as the maximum practical size for minimum lag of a service type pitot-static tube, this system was used as a basis for comparison of the other pitot-static tube designs. Figure 14 provides a graphical comparison of the lag effects of the five pitot-static tubes on the F-106 aircraft central air data computer utilizing 3/8 inch O.D. connecting tubing throughout. At 40,000 feet altitude the minimum lag constant of 0.126 seconds was obtained with the 3/8 inch O.D. tubular chamber and the other chamber designs produced lag constants as high as 0.902 seconds with the MA-1 development tube. This latter time constant is 7.16 times greater at 40,000 feet than that of the optimium tube design. It is interesting to note the large lag constant caused by the standard AN5816 pitot-static tube and especially the magnitude of the lag at sea level in comparison to the other designs tested. This effect is caused by the small 3/16 inch O.D. tube leadout from the static pressure chamber to the connecting tubing. The MA-1 production pitot-static tube with annular chamber exhibited a lag effect practically equal to that of a single ¼ inch O.D. tubular chamber.

One single 3/8 inch O.D. line still proved to be the most satisfactory from a lag standpoint as established in the primary report. A comparison of the lag associated with these three systems is shown in Figure 15. It appears that there is a point at which, for large instrument volumes and extensive tubing lengths (such as in wing boom mounted pitot-static installations), two ¼ inch O.D. tubes will produce a lag constant for the C.A.D.C. that is slightly smaller than that produced by a single 3/8 inch O.D. tube. From a weight standpoint the twin ¼ inch O.D. lines penalize the system considerably. In general, the best combination for weight, lag and simplicity of installation is obtained with 3/8 inch O.D. X 0.035 tubing.

SECTION III

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are presented concerning the results of the investigation into the effects of the pitot-static tube design on static pressure lag:

1. The static pressure chamber design of the pitot-static tube can be the critical factor in the total static pressure system lag.

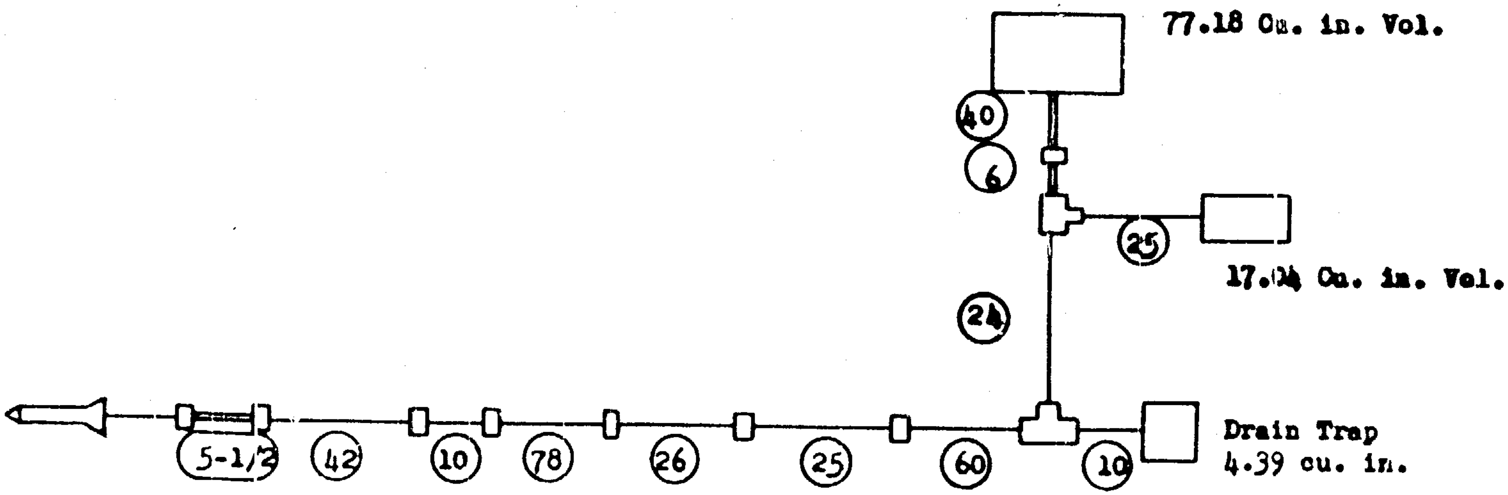
2. Tubular static pressure chambers no smaller than 1/4 inch inside diameter are recommended. If an annular chamber is necessary, it should be a minimum of 3/16 inch equivalent diameter.

3. The AN5816 pitot-static tube produces a lag factor which is excessive for high performance aircraft. It is recommended that all century series aircraft equipped with this tube be retrofitted with the 115 volt Type MA-1 pitot-static tube or its 28 volt counterpart, the Type TRU-1/A tube.

4. Future pitot-static tube designs should be carefully analyzed as to the lag factor resulting from the internal design. The basic theory accurately defines the response characteristics of circular chambers. Additional tests may be required if the design differs radically from the circular cross section.

Figure 1

F-106 Static Pressure System #1



NOTE: (a) Indicates 3/8 inch O.D. Aluminum Tubing.

(b) Indicates 1/4 inch O.D. Aluminum Tubing.

(c) Circled Figures are in inches.

FIGURE 2

Modified F-106 Static Pressure System #2

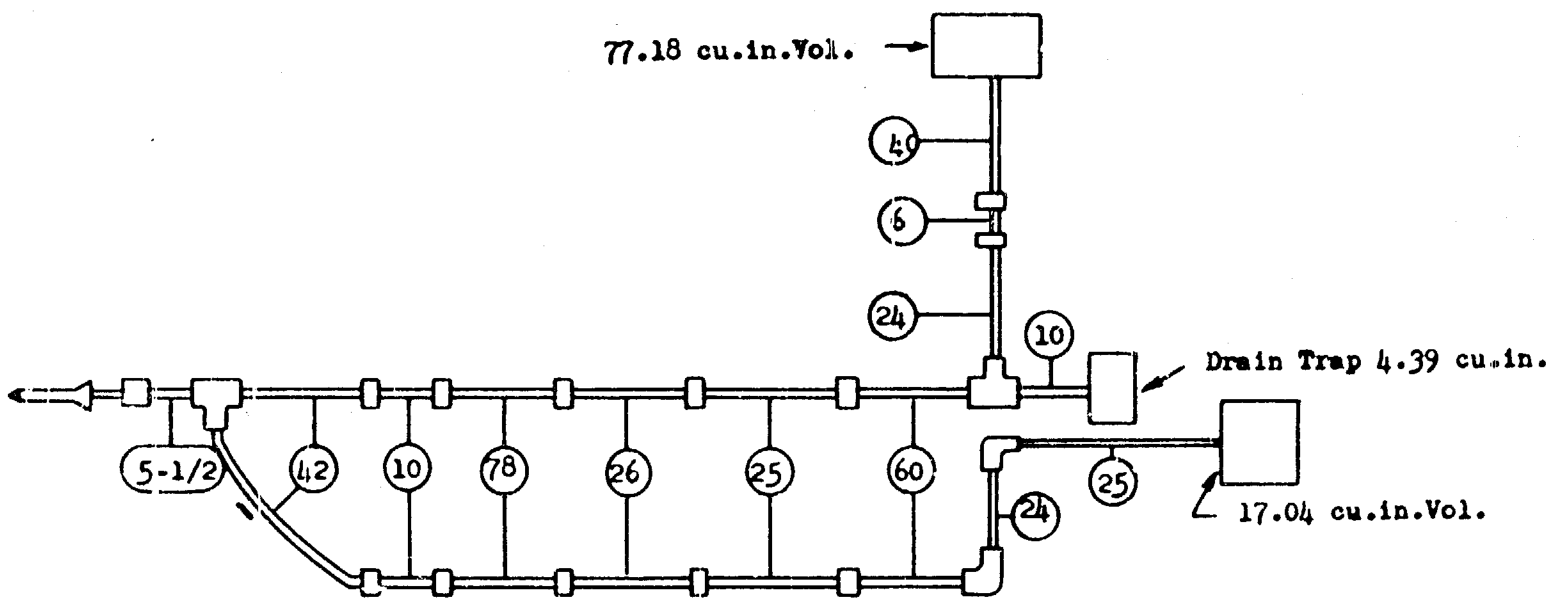


FIGURE 4

3/8 inch O.D. x 0.035 inch Tubing

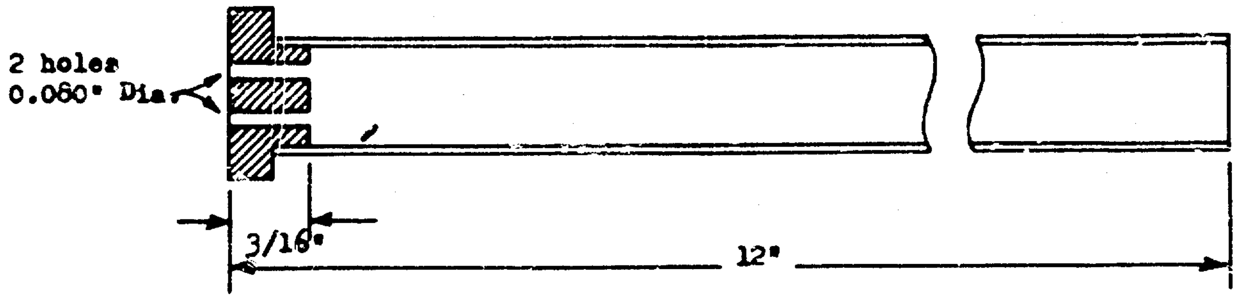


FIGURE 5

1/4 inch O.D. x 0.035 inch Tubing

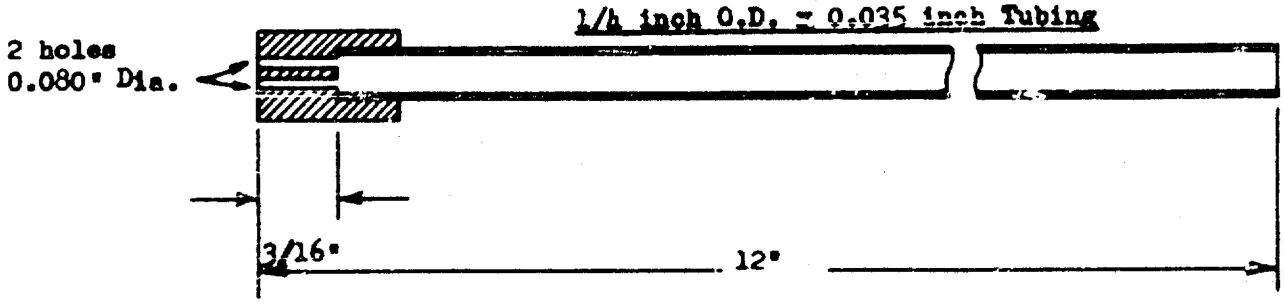


FIGURE 3

MA-1 Pitot-Static Tube

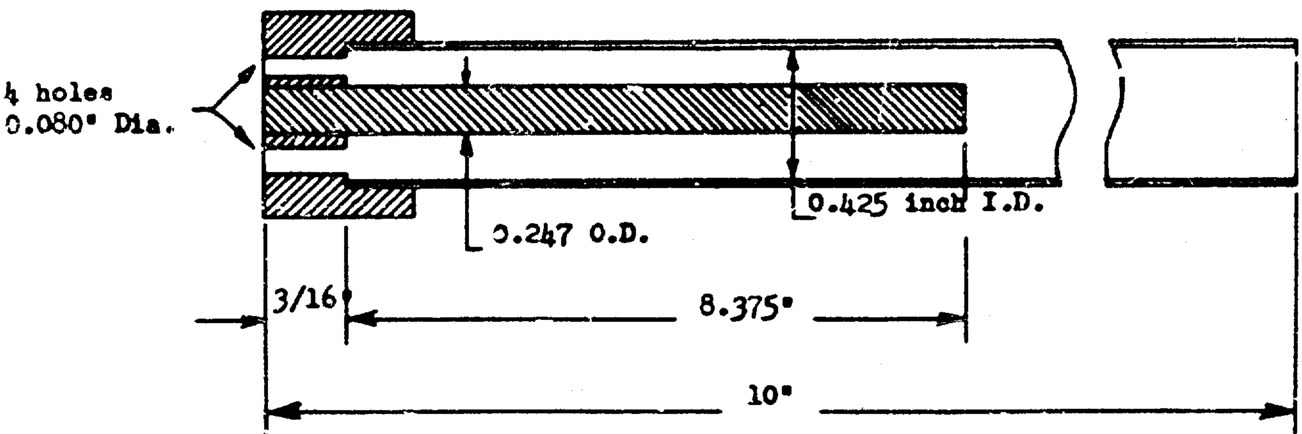
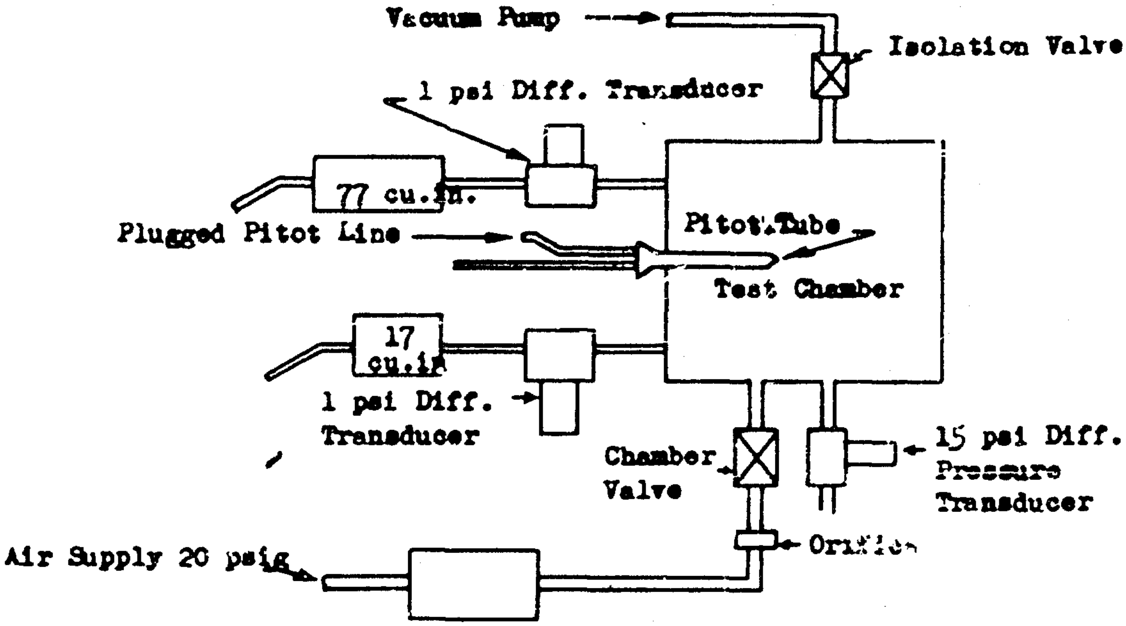
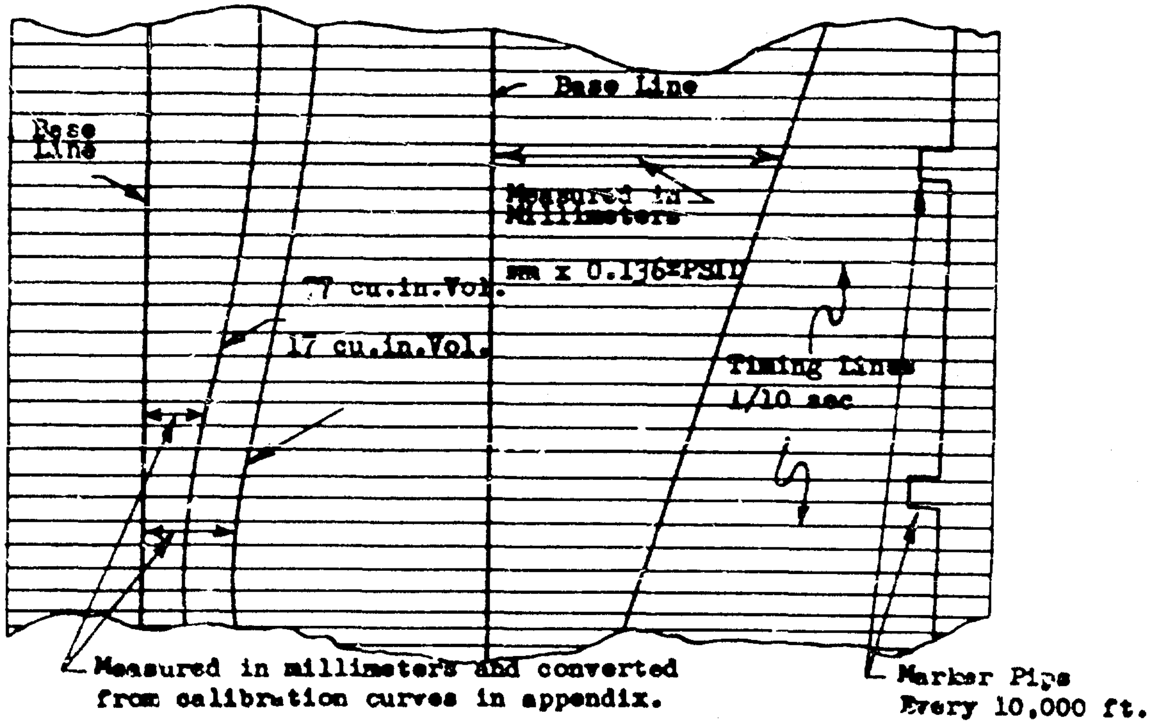


FIGURE 6

CHAMBER LAYOUT



Sample Recording of Differential Pressure at Various System Volumes



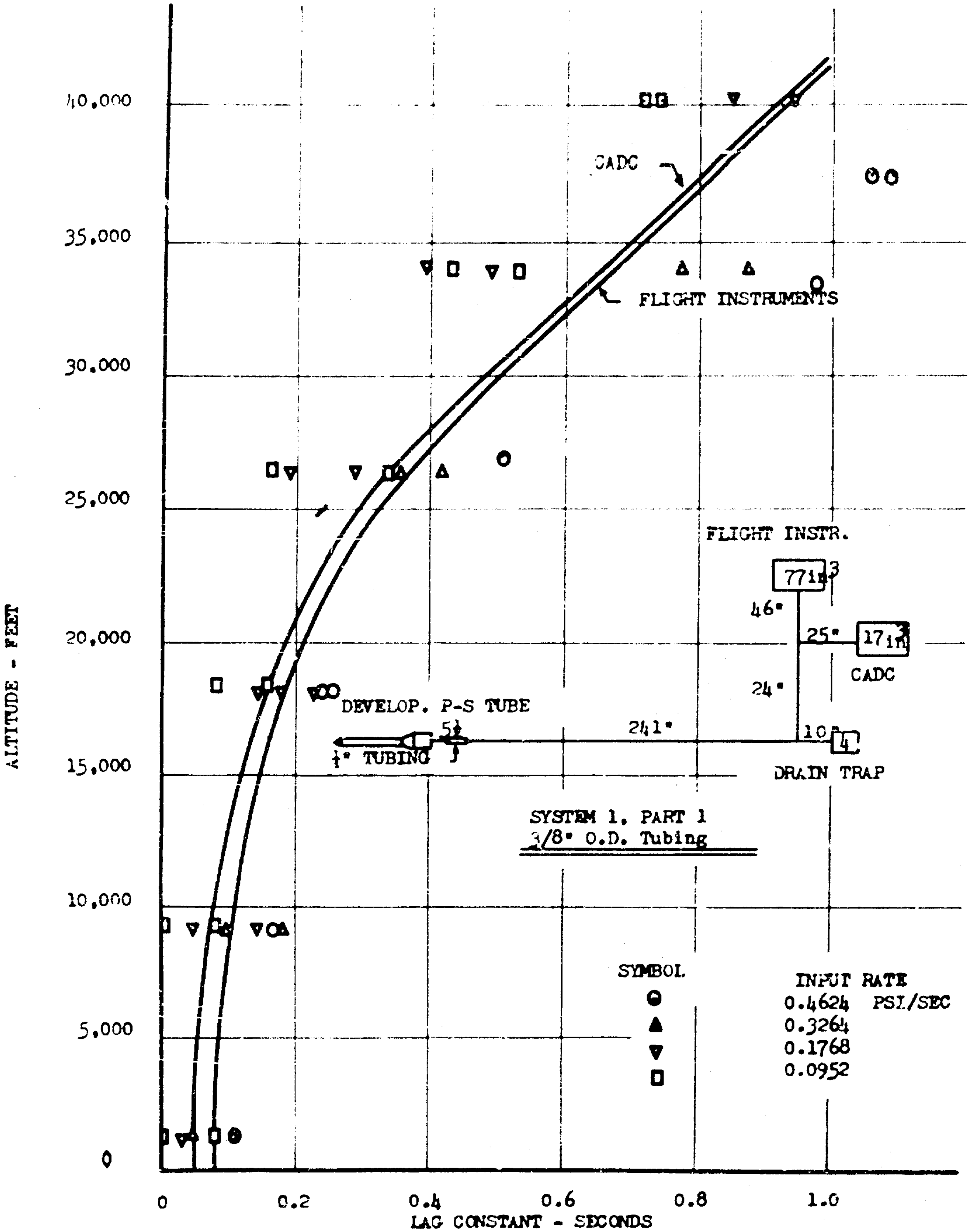


FIG. 7 - VARIATION OF LAG CONSTANT WITH ALTITUDE FOR SYSTEM 1, PART 1

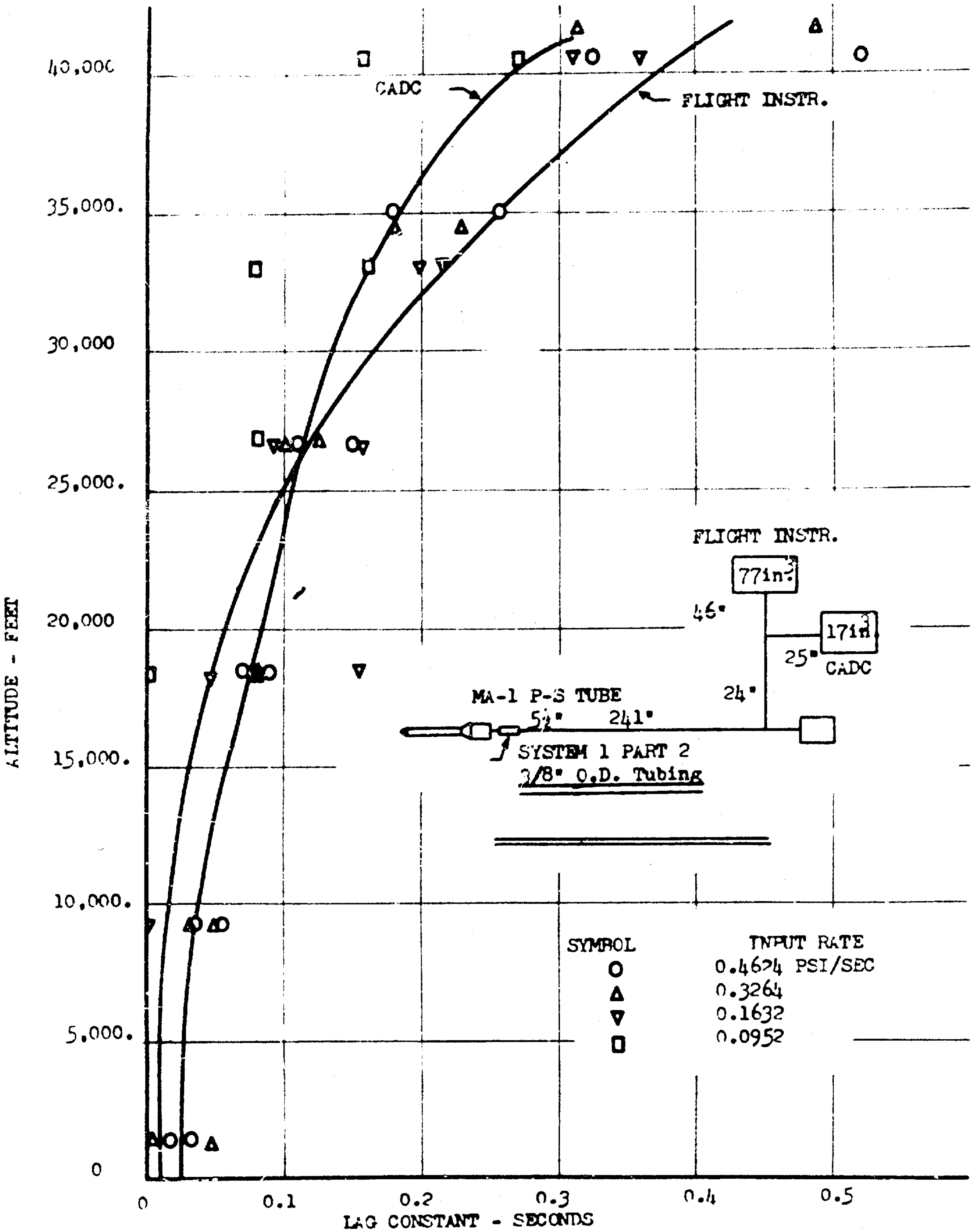


FIG. 8 VARIATION OF LAG CONSTANT WITH ALTITUDE FOR SYSTEM 1, PART 2

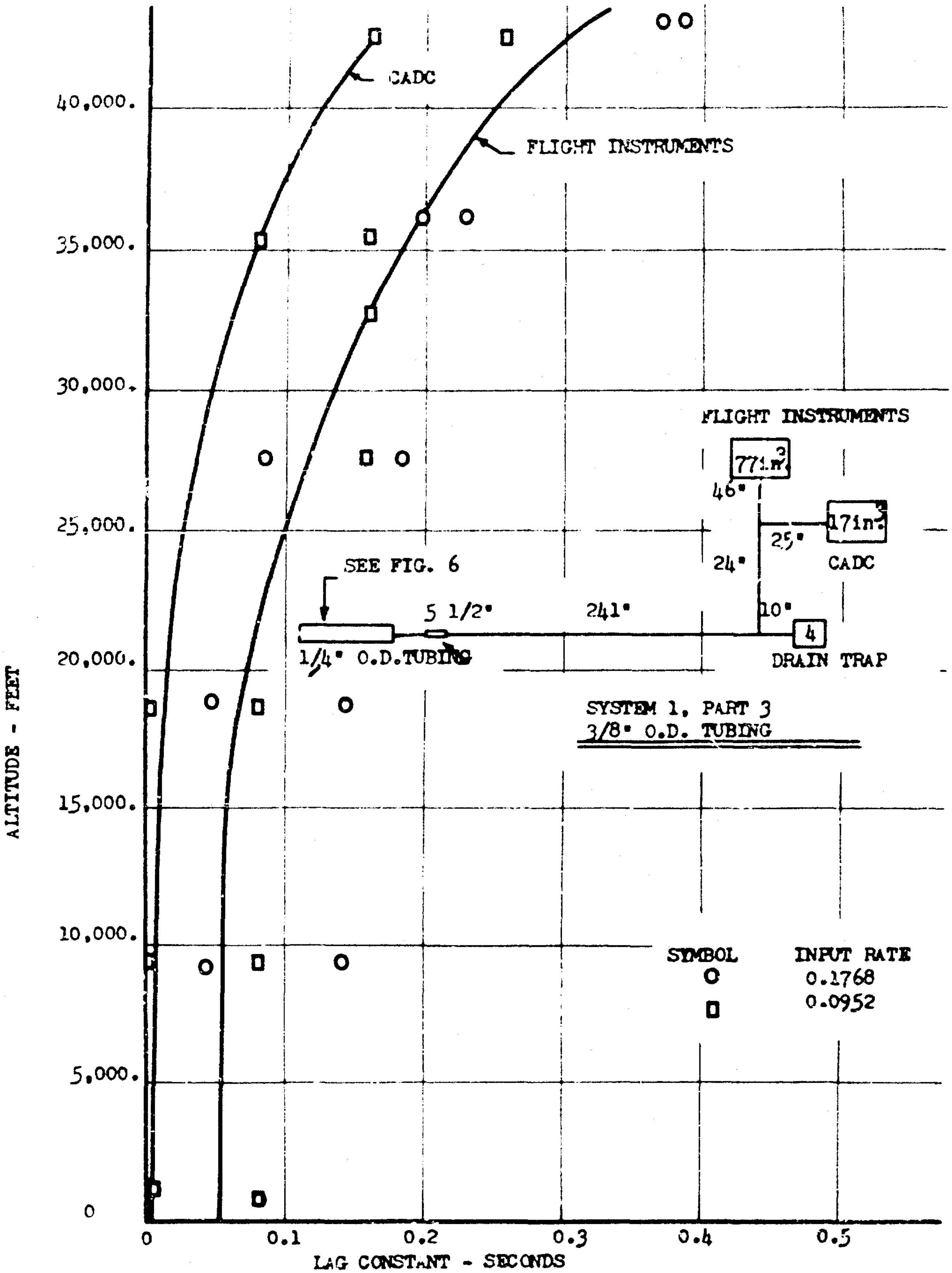


FIG. 9 - VARIATION OF LAG CONSTANT WITH ALTITUDE FOR SYSTEM 1, PART 3

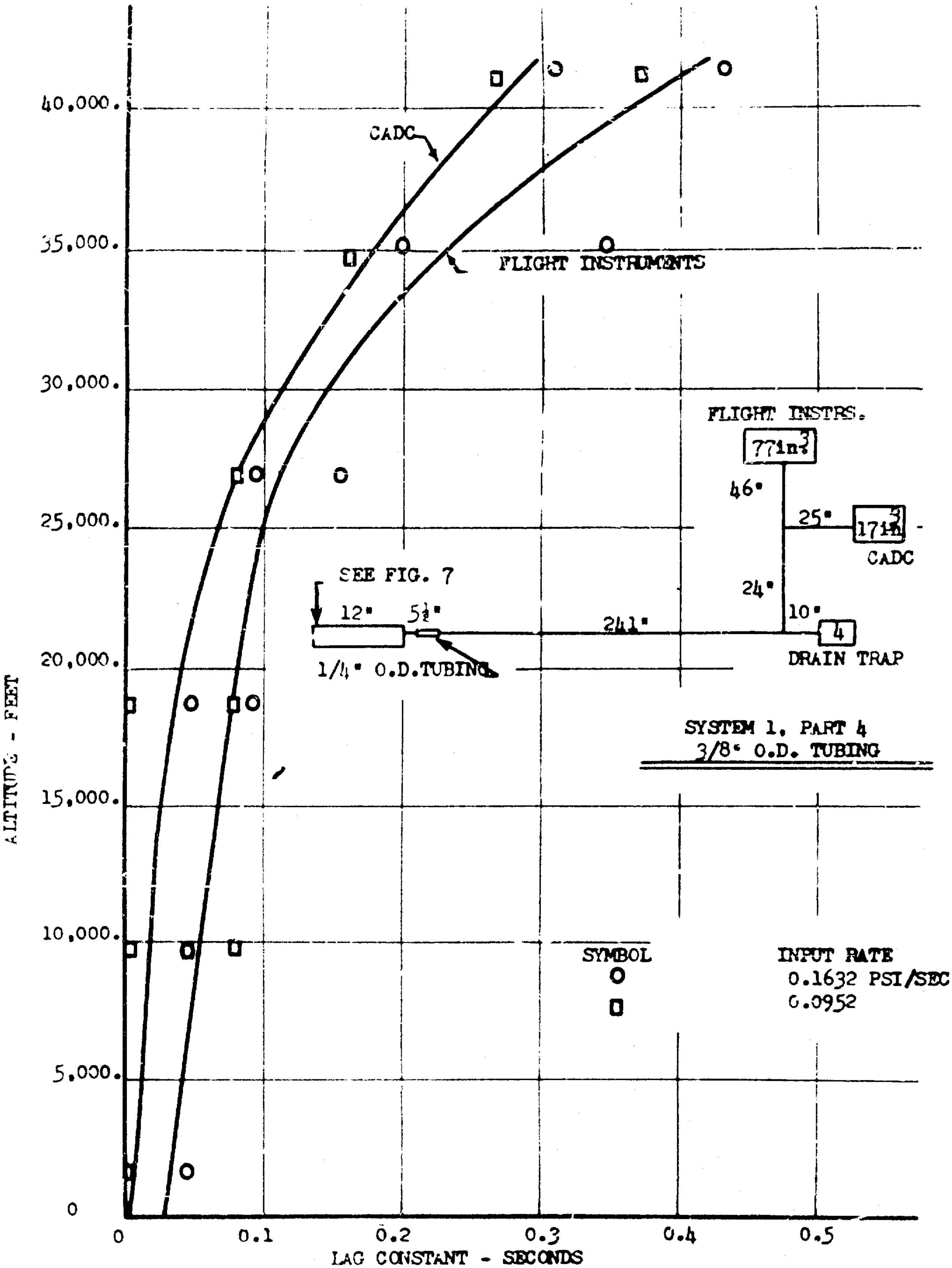


FIG. 10 - VARIATION OF LAG CONSTANT WITH ALTITUDE FOR SYSTEM 1, PART 4

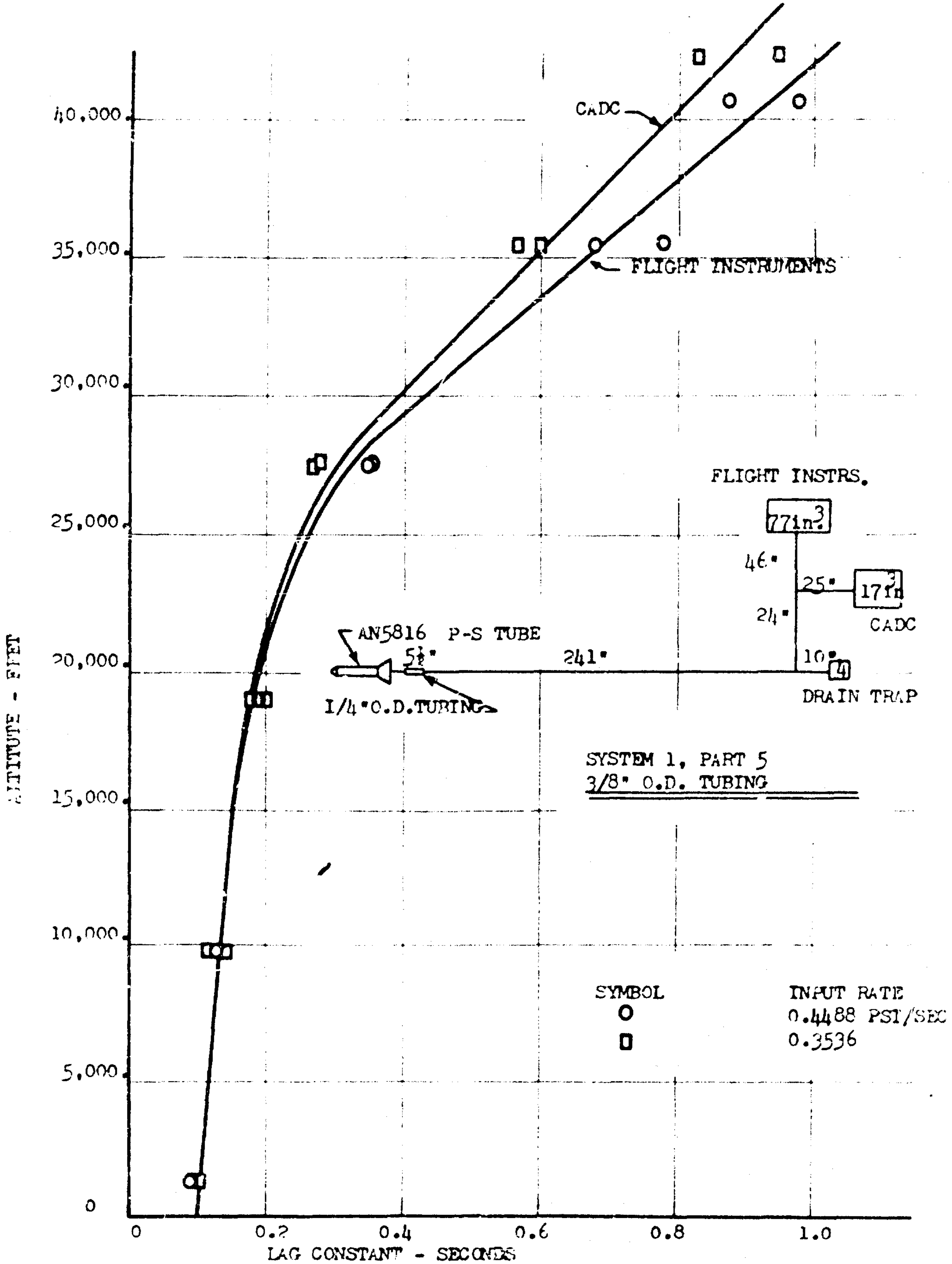


FIG. 11 - VARIATION OF LAG CONSTANT WITH ALTITUDE FOR SYSTEM 1, PART 5

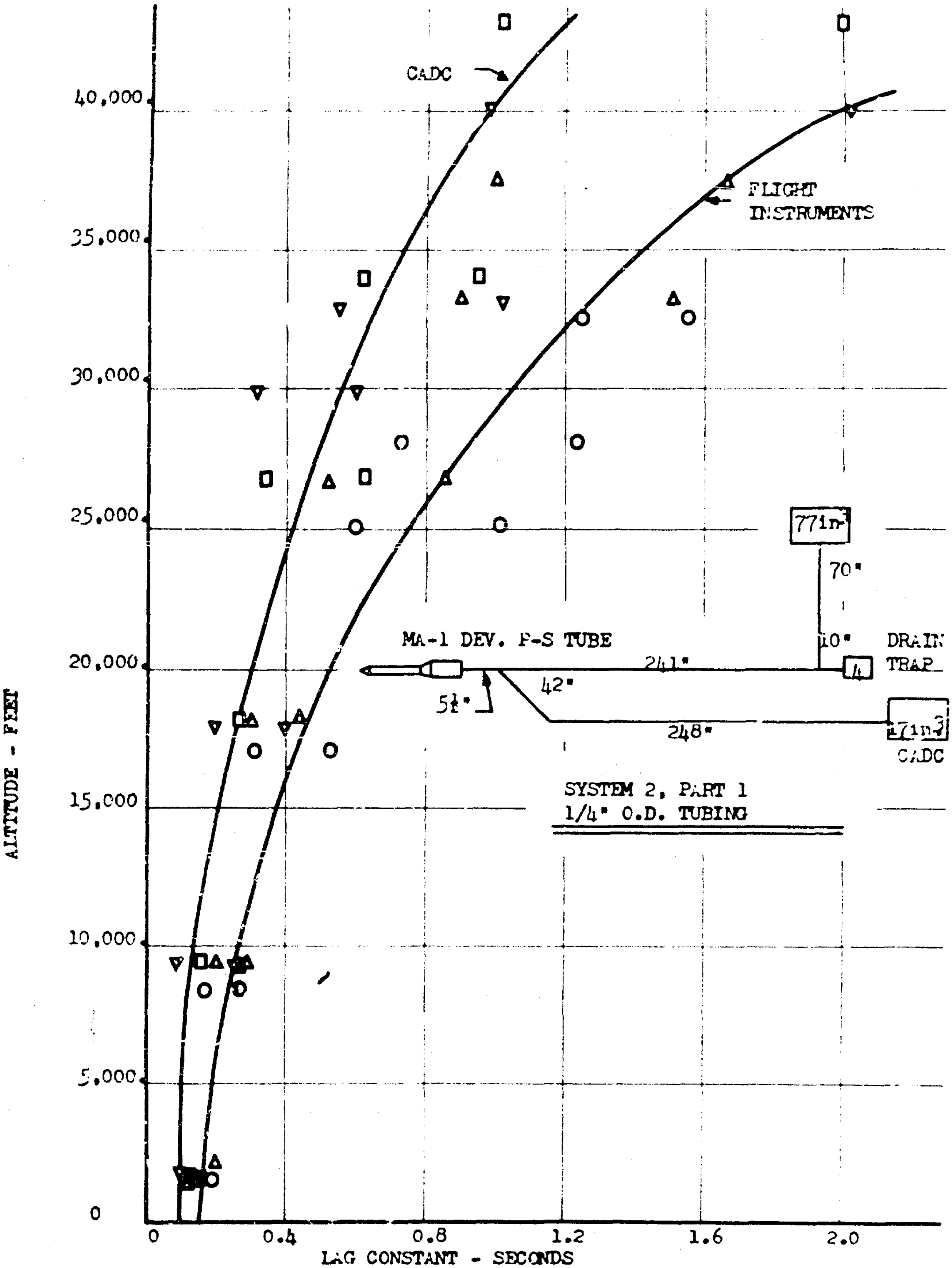


Fig. 12 - VARIATION OF LAG CONSTANT WITH ALTITUDE, SYSTEM 2, PART 1

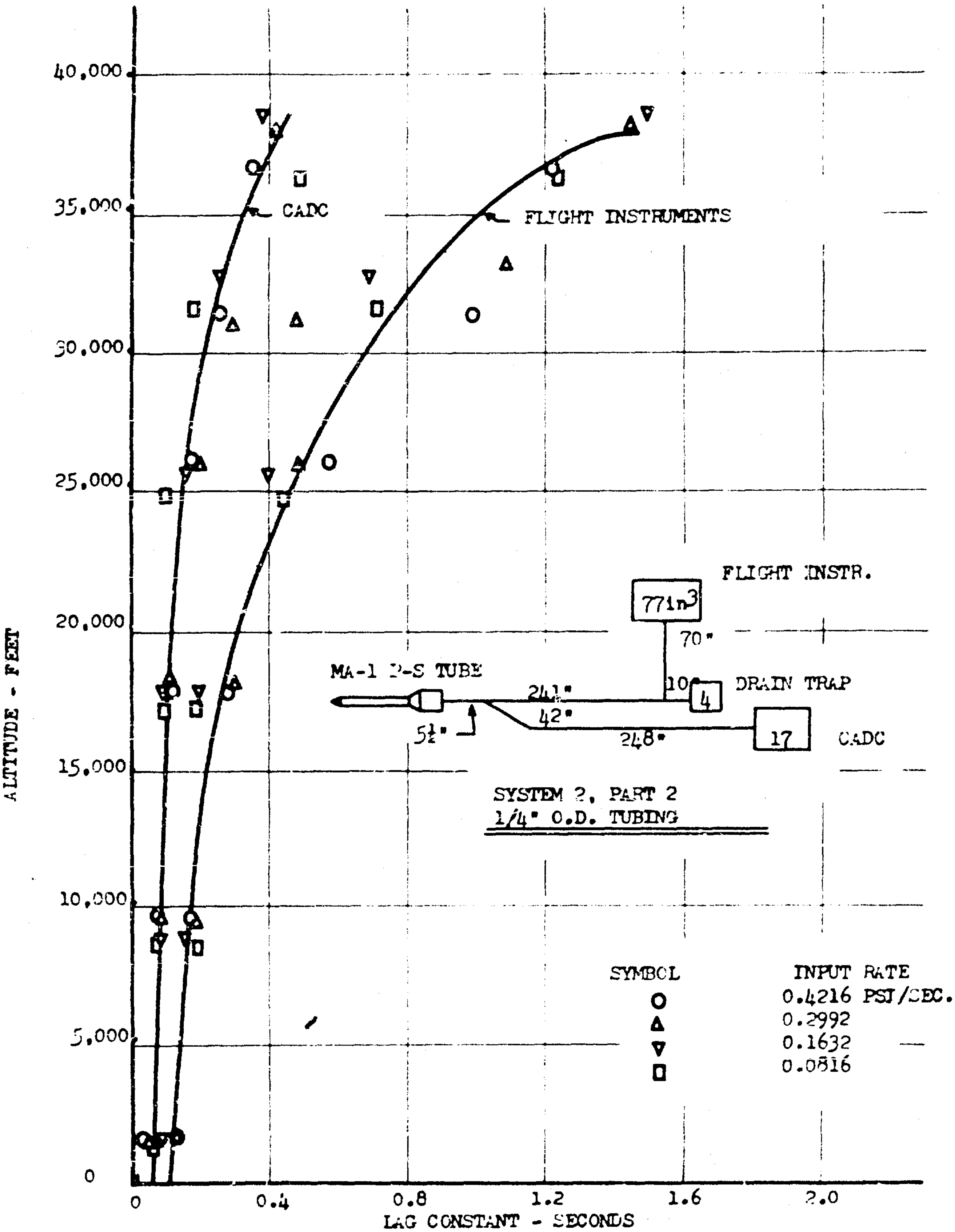


FIG. 13 - VARIATION OF LAG CONSTANT WITH ALTITUDE FOR SYSTEM 2, PART 2

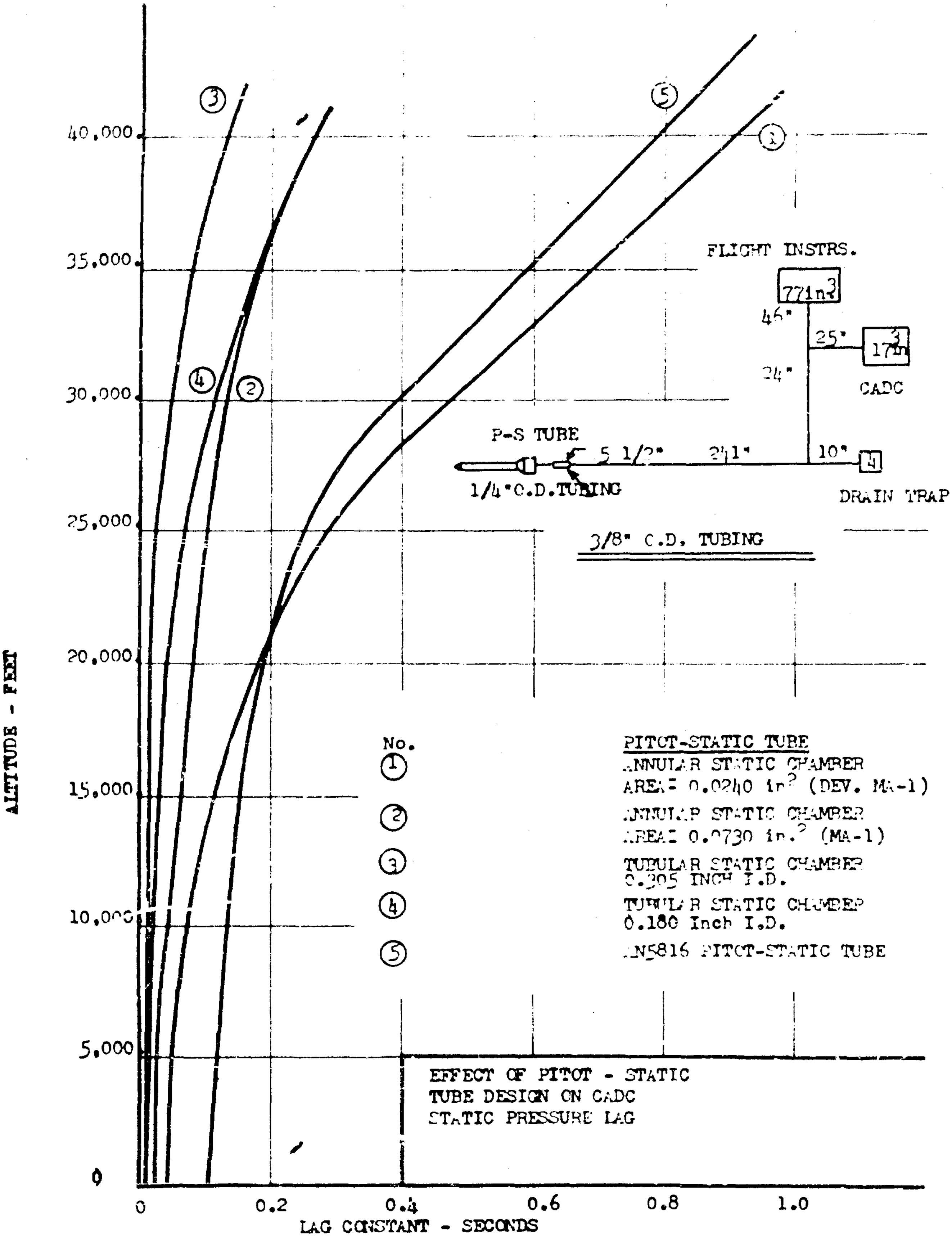


FIG. 14 - COMPARISON OF FIVE STATIC PRESSURE CHAMBER DESIGNS EFFECT ON LAG TO CADC

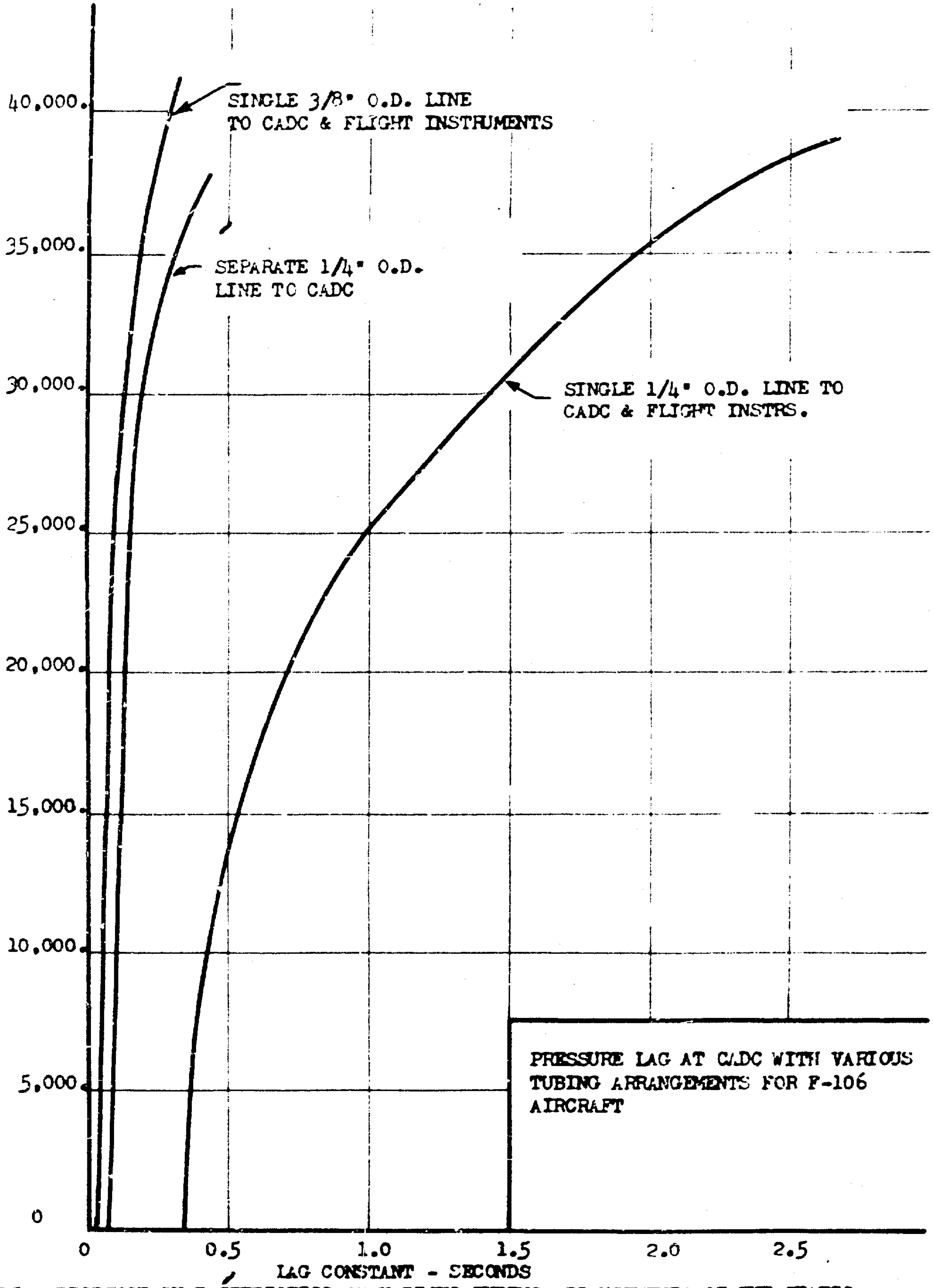


FIG. 15 - RESPONSE CHARACTERISTICS OF VARIOUS TUBING ARRANGEMENTS OF THE STATIC PRESSURE SYSTEM OF THE F-106A AIRCRAFT.